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CERTIFICATE

This certificate is issued in support of an application for Patent registration in a country outside New Zealand pursuant to the Patents Act 1953 and the Regulations thereunder.

I hereby certify that annexed is a true copy of the Provisional Specification as filed on 17 June 2002 with an application for Letters Patent number 519609 made by LANDCARE RESEARCH NEW ZEALAND LIMITED.

Dated 3 July 2003.

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Neville Harris

Neville Harris
Commissioner of Patents

Patents Form No. 4

PATENTS ACT 1953

PROVISIONAL SPECIFICATION

MOISTURE CONTENT DATA SYSTEM AND METHOD

We, **LANDCARE RESEARCH NEW ZEALAND LIMITED, a New Zealand company, of Canterbury Agriculture & Science Centre, Gerald Street, Lincoln, New Zealand,** do hereby declare this invention to be described in the following statement:

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FIELD OF INVENTION

The invention relates to an automated system and method for obtaining moisture content data to estimate moisture release curves, particularly designed to obtain drying and wetting water release curves for an undisturbed or remoulded soil sample.

BACKGROUND TO INVENTION

One of the most important soil physical relationships requiring estimation is the amount of water available in the soil represented by a water retention curve. A water retention curve represents the relationship between soil water tension (matric potential) and soil water content of the soil. Many models have been developed to estimate the amount of water available in soil from small farm lands to large scale catchments. The soil water retention curve plays a major role in many of these models to achieve their objective. Studies of water balance and run of generation leading to sediment production require the properties of soil water retention curve at the lower end (0 to 100 cm soil water tension).

The most popular and only reliable method to obtain the soil water retention curve at the lower tension is a tension table with a hanging water column. This method has been in use for this purpose for over 50 years. A tension table is made out from a porous material such as ceramic or a sand bed. Since larger pore space dominates the soil water characteristics at the lower tension range tests must be carried out with minimum disturbance, or no disturbance to the soil sample.

To use the tension table, first the soil sample must be saturated. During the saturation, weight of the soil sample is checked regularly to find the equilibrium point. Once the saturation processes is completed different tensions are applied to the soil sample sitting on the tension table, by the hanging water column. In order to find the equilibrium point for each applied tension the water meniscus in the hanging water column is monitored regularly. This is a very time consuming task. Once the soil sample reaches the

equilibrium condition it is transferred to a weighing apparatus at the end of each tension step to estimate the moisture content.

The main disadvantages of this method are.

1. The disturbance to the fragile soil matrix (larger pore structure) due to regular handling of the soil sample .
2. Inaccuracy soil moisture estimation due to sample handling.
3. Labour intensive task (Regular supervision is necessary to determine the equilibrium points).

It would be useful to at least partially automate the test procedure in order to eliminate or reduce the drawbacks. An added advantage of an automated system could be the ability to produce accurate outflow data to estimate the unsaturated hydraulic conductivity.

SUMMARY OF INVENTION

In broad terms in one form the invention comprises a moisture content data system comprising a porous plate arranged to support a soil sample for which a moisture release curve is desired; a hanging water tube extending downwardly from the porous plate, the tube arranged to convey liquid toward and away from the porous plate; a measuring capillary tube extending from the hanging water tube, the measuring capillary tube substantially parallel to the porous plate; measurement apparatus configured to measure the displacement of liquid along the measuring tube; and a programmable micro controller configured to receive and store displacement of water volume from the soil sample for calculating a moisture release curve and unsaturated hydraulic conductivity of the soil sample.

Preferably the measurement apparatus comprises a series of infrared emitter and infrared detector pairs spaced along the measuring tube to measure the water displacement in real time.

In broad terms in another form, the invention comprises a method of measuring moisture content comprising the steps of supporting a soil sample for which a moisture release curve is desired on a porous plate; positioning a hanging water tube extending downwardly from the porous plate and arranged to convey liquid toward and away from the porous plate; connecting a measuring capillary tube to the hanging water tube, the measuring capillary tube substantially parallel to the porous plate; measuring the displacement of liquid along the measuring tube; receiving and storing displacement of liquid volume data from the soil sample; and calculating a moisture release curve and unsaturated hydraulic conductivity of the soil sample from the data represented by displacement of water volume.

BRIEF DESCRIPTION OF THE FIGURES

Preferred forms of the moisture release curve calculation system and method will now be described with reference to the accompanying Figures in which:

Figure 1 is a preferred form system of the invention;

Figure 2 shows a hardware user interface apparatus forming part of the system of Figure 1;

Figure 3 shows a software user interface forming part of the system of Figure 1;

Figure 4 shows a set up window from the interface of Figure 3;

Figure 5 shows a collect data window from the interface of Figure 3;

Figure 6 shows a status panel forming part of the interface of Figure 3;

Figure 7 shows a manual control button forming part of the interface of Figure 3;

Figure 8 illustrates sample raw data from the system of Figure 1;

Figure 9 shows typical outflow data;

Figure 10 shows the amount of water retaining in a soil sample;

Figure 11 shows a sample moisture release curve;

Figure 12 illustrates water retention in a soil sample; and

Figure 13 illustrates a moisture release curve.

DETAILED DESCRIPTION OF PREFERRED FORMS

Figure 1 shows a schematic representation of one form of the invention 10. A soil sample retaining ring 20 is positioned on a porous plate 40 which is rigidly connected to a sealed water reservoir 35. The porous plate 40 and the water reservoir beneath it rests on the structural support or base 30, as a single unit. The porous plate is constructed of a suitable material which is permeable to liquid such as water. The porous plate is preferably of a high flow type with an air entry value of 0.5 bar. Inside the sealed water reservoir 35 a channel is formed in a shape of a spiral. The soil sample retaining ring 20 is preferably removably supported on the porous plate 40, and the join between the soil sample retaining ring 20 and porous plate 40 is coated with a suitable water impermeable material such as silicon grease in order to ensure a proper seal between the soil sample retaining ring and the porous plate.

The retaining ring 20 contains the undisturbed or remoulded soil sample 50 for which a moisture release curve is desired. Extending downwardly from one end of the spiralled channel in the sealed water reservoir below the porous plate 40 is a hanging water tube 60. This tube is arranged to convey liquid, for example water, upwardly toward and through the porous plate 40 where required and to also convey water away from the

porous plate 40 where required. An air valve 70 fitted at the other end of the spiral shaped channel in the water reservoir releases any air trapped in the tubes through air valve 70 during a purging cycle as described below.

A water receptacle or tank 100 containing a liquid such as water 110 supplies de-aired water to the rest of the system 10 through supply tube 120. This de-aired water 110 is used to fill the hanging water tube 60 and a measuring capillary tube described below and saturate the soil sample 50. The water tank 100 is preferably elevated with respect to the soil sample 50 to exert sufficient pressure difference to force the water from the tank 100 through the sealed water reservoir 35 and porous plate 40 to the soil sample. The water supply tube 120 is preferably fitted with a suitable tank valve 130 to control the flow of water exiting the tank 100 to the rest of the system.

The hanging water tube 60 is also fitted with a suitable sample valve 140 to control the flow of water from the water tank 100 travelling into and up the hanging water tube 60, and to control the flow of water exiting the tube 60. A drain valve 150 is arranged to control the flow of water out of the supply tube 120 and the hanging water tube 60.

A measuring capillary tube 200 is connected to the ends of the hanging water tube 60 and the supply tube 120. The horizontal measuring tube 200 is vertically positioned with respect to the soil sample 50 by a distance "d" in order to apply tension to the soil sample 50. It is envisaged that the distance "d" can be varied in order to alter the applied soil water tension on the soil sample 50. The distance "d" could be varied by enabling the measuring tube 200 to be raised and lowered with respect to the soil sample 50 using a stepper motor (not shown) in order to apply different soil water tension to the soil sample.

The measuring capillary tube 200 is substantially horizontal and parallel to the porous plate 40 and it is fitted with measurement apparatus to measure the displacement of of water along the tube 200 in either direction.

In one form, the measurement apparatus includes a series of infrared emitters positioned on one side of the measurement tube 200, together with a series of corresponding infrared detectors 220. The emitters 210 and detectors 220 are preferably arranged as corresponding pairs. Modulated infrared beams at 40 kHz are transmitted from the infrared emitters 210 to the infrared detectors 220 through the measurement tube 200.

It is envisaged that part of the measuring tube 200 will contain water and that a meniscus appears at the intersection between the part of the tube 200 filled with water and the part of the tube which does not contain water. The meniscus will travel along the measuring tube 200 as water enters or exits the tube 200.

Each pair of emitters and detectors preferably defines a segment of the measuring tube 200, the amount of water in each segment is pre-determined. Each segment could hold, for example, 0.155ml of water. The meniscus described above will obscure the infrared beams as it passes between an emitter/detector pair and so indicate the direction of water movement and the number of water filled segments in the measuring tube 200.

The horizontal measuring tube can be withdrawn for cleaning or can be replaced with a smaller diameter measuring tube 200 increase the resolution as desired.

The system 10 further comprises hardware user interface 300 including a programmable micro controller which is configured to receive, processes and store data from the measuring tube 200 and control the rest of the system according to the user entered programme stored in the micro controller. The hardware user interface 300 includes a suitable data port to which a personal computer or workstation 400 can be connected. The computer 400, running appropriate software, sends the required configuration to the micro controller to perform the test. It is also configured to receive data stored in the micro controller, to process and to generate a series of moisture release curves for the soil sample 50.

Figure 2 shows the front panel of one form of the hardware user interface 300. The hardware is preferably connected to a power supply using two separate 12 volt lines. One line is for the motor and solenoids using a 5 Amp fuse, the other 12 volt line is for the electronics and uses a 2 Amp fuse.

The hardware user interface 300 is provided with a power switch 310, a series of pilot lights showing status and current operation of the system 320 and an RS232 serial port 330 for connection to a personal computer or workstation. The hardware user interface is also provided with a display panel 340 for displaying instructions and current progress of the system to a user of the system and status information.

The apparatus also includes several button controls, for example Bypass the current tension step 350, Start the test 360 and activate the Display 370. The functions of these controls will be described below.

The hardware user interface 300 further includes a series of LED displays 380. The number of LED displays illuminated indicates the number of water segments in the measuring tube 200 from Figure 1 which are full of water. For example, if 4 LED displays are illuminated, then 4 segments in the measuring tube 200 are full of water, with each segment containing approximately 0.155ml of water.

In order to obtain drying and wetting moisture release curves of a soil sample, the system 10 from Figure 1 is placed through one or more purging, drying and wetting cycles.

The intention of the purging cycle is to remove air bubbles from tube 60, 120, 200 the porous plate 40 and the water reservoir 35. Referring to Figure 1, the distance d is reduced to the minimum distance by, for example raising the measuring tube 200 to an upper limit. First valves 140 & 150 are closed and the valve 130 is opened to fill the measuring tube 200 with de-aired water from tank 100. Then valve 140 and 70 are opened while closing valve 130 allowing water and trapped air bubbles in the tubes to flow through tube 60 and along the spiralled water channel in the sealed water reservoir

35 and escape through air valve 70. Any air trapped in the tubes will escape through the air valve 70 .

It is envisaged that this purging process be repeated 20 times or in any case enough times so that the water volume through the system is replaced in all the tubes.

Following the purging cycle, a drying cycle imposes a tension on the soil sample 50 by lowering the measuring tube 200 to a height corresponding to the tension required to remove water from the soil sample. The measuring tube 200 is first emptied, by opening the valve 150 leaving all other valves closed. Valve 150 is closed as soon as the water meniscus inside the measuring tube 200 reaches the first IR sensor at the right end of the measuring tube 200. With all valves closed valve 140 is then opened to enable water to release from the soil 50 to pass through the porous plate 40 down the hanging water tube 60 to the measuring tube 200.

As the water passes along the measuring tube 200, the water meniscus will trigger the emitter/detector pairs positioned along the measuring tube 200 and in this way, the direction of the water movement and the magnitude of the displacement of water along the measuring tube 200 is measured.

Water in the measuring tube 200 drains automatically from the tube when all segments in the measuring tube 200 are full of water. All the activities of the system 10 are preferably controlled by a PIC16F877 Microchip® micro controller according to the user entered program stored in it. It decides when to empty the measuring tube 200 by counting the number of active infra red receivers in the measuring tube. It drains the tube as the number of filled segments reaches 6 during a drying or purging cycle. It re-fills the measuring tube as the number of active segments reaches zero during a wetting cycle.

The Micro controller records the active segment number in real time as the water meniscus passes between each IR beam. In this way the amount of water taken by the soil sample during a wetting cycle and the amount of water released by the soil sample

50 during drying can be estimated. The Micro controller estimates the time elapsed since the water meniscus in the measuring tube 200 passes a segment and compares it with the pre detetermined time limit. In one form a user could specify a predetermined time limit for the water meniscus in the measuring tube 200 to move between two segments for each applied soil water tension. The time limit is the maximum time allowed for the water meniscus to travel between two segments under a given tension. If no water movement is detected in between two IR beams in the measuring tube 200 during this predetermined time limit the user could assume that the soil sample has reached equilibrium under the current tension. Referring to Figure 2, the user could press the Bypass button 350 to move onto the next cycle should the user decide that the predetermined time limit already programmed into the micro controller is too large . Alternatively, the system could be configured to move to the next cycle automatically as soon as the specified equilibrium time limit has been reached.

Once the drying cycle has been completed, a wetting cycle is then commenced if programmed by the user which enables the sample to absorb water from the measuring tube 200. Valves 140 and 150 are closed and valve 130 opened to fill the measuring tube 200 with water 110 from the tank 100. Valve 130 is then closed and valve 140 opened to enable the soil sample to enable water uptake by the sample 50. As water travels along the measuring tube 200 and up the hanging water tube tube 60, the meniscus in the measuring tube 200 will travel along the measuring tube 200 and the movement of this meniscus will be tracked by the emitter/detector pairs. Once the measuring tube 200 is empty, the valve 140 is closed and valve 130 opened to refill the measuring tube 200. Valve 130 is then closed and valve 140 opened to resume water uptake by the soil sample 50. A predetermined time limit is preferably set by the user. If no movement is measured along the measuring tube 200 during this equilibrium time period, it is assumed that the soil 50 has reached equilibrium. Alternatively, the user could press the Bypass button 350 to complete the wetting cycle.

A personal computer 400 is connected to the Serial port 350 to configure the system 10. Software running on the personal computer 400 provides a graphical user interface to control all the valves and movement of the measuring tube.

Figure 3 illustrates a graphical user interface of software installed and operating on the computer 400. In use, the computer 400 is connected through a serial port to the hardware interface 300. Clicking on the Set up Ports and Files button 420 brings up window 430 shown in Figure 4. The select port button 422 enables a user to select the COM port on the computer 400 which will be used and to specify the appropriate baud rate. The user could select, for example, a baud rate of 9,600.

Once the port is set up, Wake up J&J button 430 is selected by the user to start data communication between the computer 400 and the hardware interface 300. Data is retrieved from the interface 300 in order to populate panels 440 and 450 which represent previously programmed values. Using panel 460, the user specifies new parameters for a soil sample, using the previous values in panel 440 as a guide. In panel 460, the user may specify the number of drying and wetting cycles, the number of suction steps, and the time limit for the saturation process. The value of 2 will result in two drying cycles and two wetting cycles. The user may specify the number of suction steps up to a maximum of 10. The suction steps are also referred to as tension steps. The user may also specify a predetermined time limit for the saturation process. A value of 1 minute means that the saturation process will be terminated if the soil sample does not cause one segment of movement in the measuring tube 200 during a 1 minute period.

In panel 470, the user can specify, for each suction or tension step, a tension value and a time limit. The tension value represents the distance d between the soil sample 50 and the measuring tube 200. In this preferred form, the tension values are in multiples of 8cm and the maximum tension for a single step, or the sum of all steps, must be less than or equal to 96cm. In the example, the user has selected tension values of 8, 16, 32, 40, 56, 64, 72, 80, 88 and 96 for the respective 10 steps. It is envisaged that the apparatus 300

control distance d and this distance d is adjusted according to the suction steps specified by the user.

The user is also able to specify three different time limits to determine the equilibrium status for a saturating, drying, and wetting cycle under a given tension . If the soil sample does not take one segment of water during the wetting process, or remove one segment of water during the drying process within the specified time limit for a particular step, then the system assumes that the soil sample has come to equilibrium under that tension value.

Once the user has entered the required data into panels 460 and 470, data representing these parameters is transferred to the hardware interface 300 and the computer 400 disconnected from the interface 300. After disconnecting the computer 400, the system 10 undergoes several purging cycles to remove air bubbles from the system. The display 340 of the hardware interface 300 displays a suitablemessage to the user that the system is being purged. The display could also show the user the purging cycle number currently being performed by the system.

Once the system is purged, the soil sample is placed on the porous plate 40 and it is envisaged that the display will instruct the user to place the sample in this way and press the Start key 360 to start the first drying cycle. The display could indicate to the user whether the system is undergoing a drying or a wetting cycle, the applied tension in centimetres applied to the soil sample 50, the volume of water taken up or expelled from the soil sample in segments, and the total time taken to take or expel these segments.

The drying or wetting cycle continues until the equilibrium time limit pre-specified by the user has been reached or the system has been bypassed with the user pressing the bypass button 350.

The display is preferably a vacuum fluorescent display (VFD) programmed to turn off after a few minutes, but can be restarted by the user pressing the Display button 370.

On completion, the display 340 displays a test completion message. The user reconnects the computer 400 to the apparatus 300 and the "Wake-Up J&J" button 430 selected by the user.

Referring to Figure 3, the user presses the "Get Data" button 480 which presents to the user the window shown in Figure 5. The user selects the "Get Data" button 482 to start collecting data from the apparatus 300. The panel shows various text messages to the user guiding the user through the process of data collection.

Once the user has collected the data from the micro controller, the user selects the "Set up Ports & Files" button 420 and selects the "Select File" button 426 shown in Figure 4. The user may then specify a file name by which to index the data retrieved from the apparatus 300 using the "Save Data" button 424.

Referring to Figure 3, panel 450 includes a "Current Progress" button 490. Clicking this button presents to a user a status panel such as that shown in Figure 6. This window displays the current progress of the system such as the number of cycles being completed, current tension and time waiting for the next water segment to be filled or emptied since the last segment is detected.

Referring to Figure 3, the panel 450 may also include a manual control button 500 enabling a user to manually control parameters of the system as shown in Figure 7, for example close or open sample valve 140, close or open air valve 70, close or open drain valve 150, close or open tank valve 130. The user may also return the measuring tube 200 or rack to a default position or may raise or lower the capillary tube.

Figure 8 shows sample raw data transferred from apparatus 300 to computer 400. The data 600 could include program parameters as a series of descriptive text strings followed by parameter values, status data 620 including a descriptive text string followed by a numerical value, suction step data 630, and a series of data strings 640. Each data string

could include, for example, a year, month, date, hour, minute, second, cycle description, for example saturation/purging cycle, drying cycle or wetting cycle, tension value, cycle number and cumulative volume as a number of segments. This cumulative volume can be multiplied by 0.155 to get the volume in mls.

The software running on the computer 400 is configured to generate a series of graphs representing the data retrieved from the apparatus 300.

Figure 9 illustrates typical outflow data for retention of 32cm of water and Figure 10 illustrates the amount of water in the soil sample estimated from the outflow data.

Figure 10 shows amount of water retaining in the soil sample in real time (Test-1)

Figure 11 shows a sample moisture release curve.(Test-1)

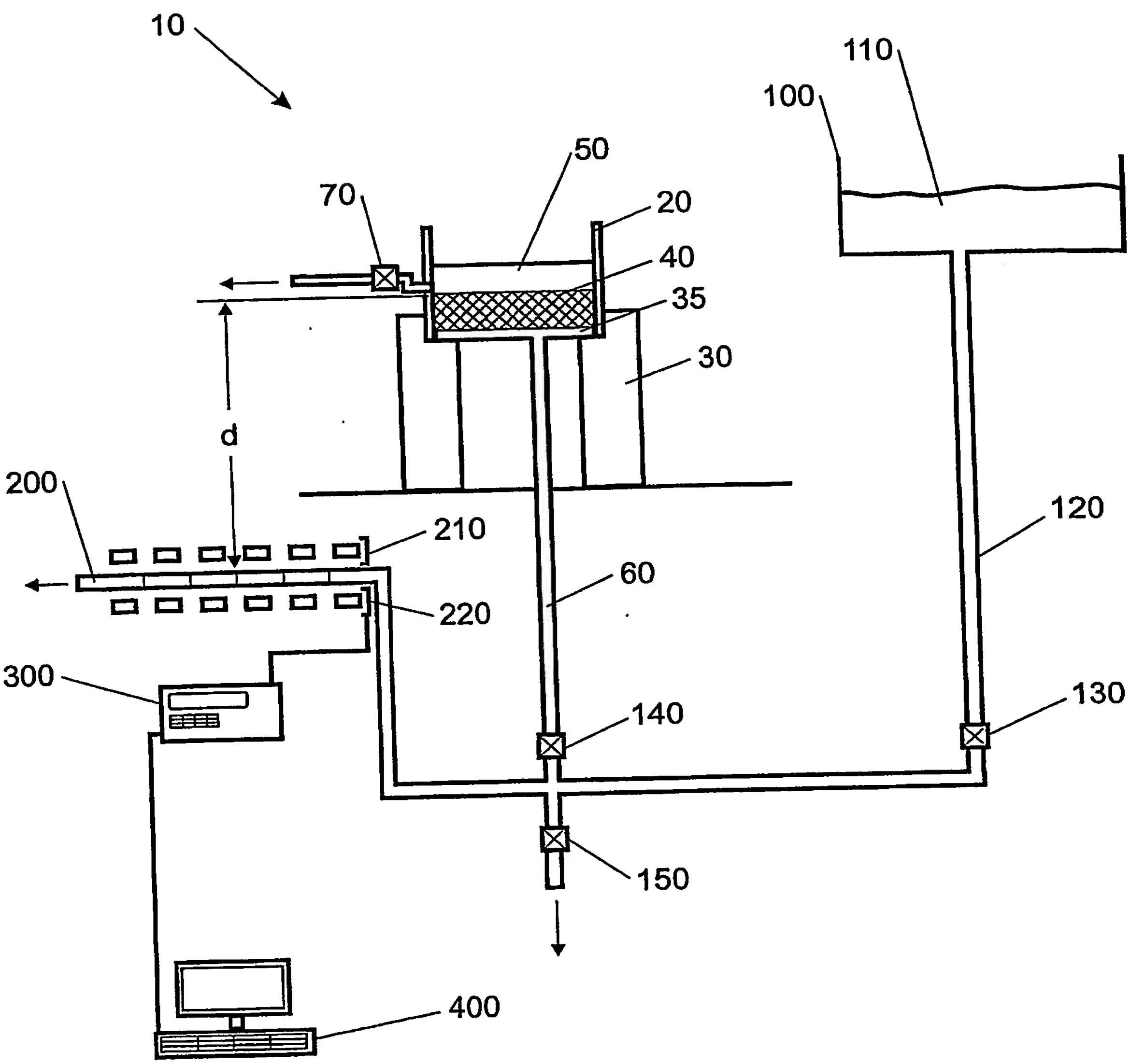
Figure 12 shows water retention in the sample from Test-2.

Figure 13 shows a moisture release curve for Test-2

The moisture release curve calculation system and method of the invention has an advantage that data is stored automatically in the micro controller EEPROM non-volatile memory. This data will remain in the memory of the apparatus 300 after power is switched off and can be transferred to the computer 400 at any time. The major advantage of this system and method is the soil sample 50 is not disturbed during measurement, resulting in more accurate measurement

The foregoing describes the invention including preferred forms thereof. Alterations and modifications as will be obvious to those skilled in the art are intended to be incorporated within the scope hereof.

Landcare Research NZ Ltd
By the authorised agents
AJ PARK
Per



10
110
100
50
70
20
40
35
30
d
200
210
220
60
120
300
140
130
150
400

FIGURE 1

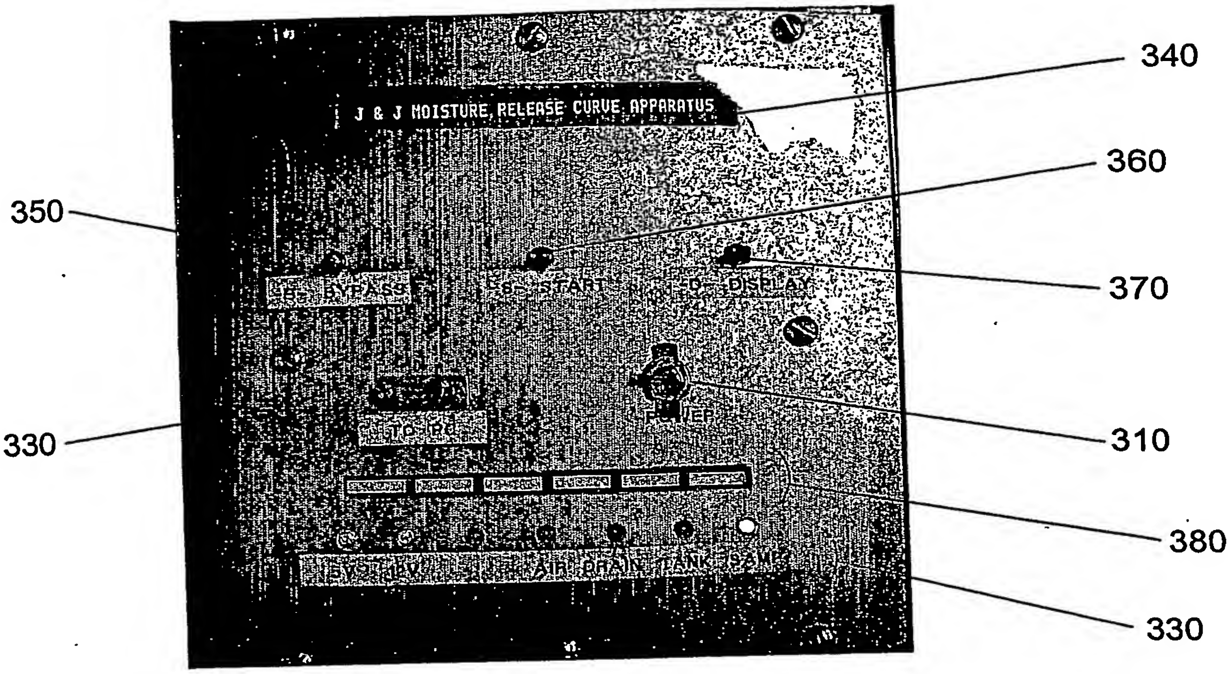
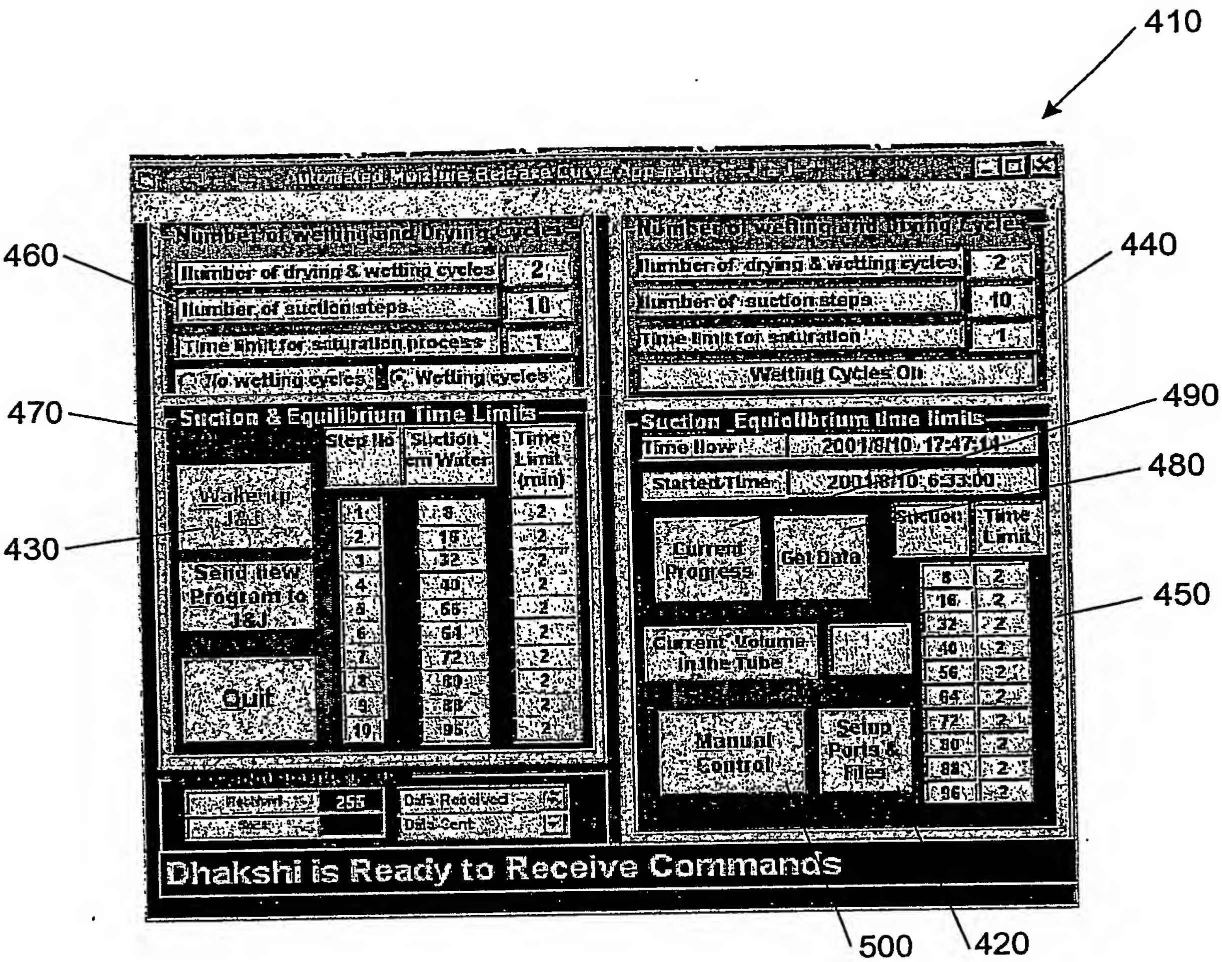

340
J & J MOISTURE RELEASE CURVE APPARATUS
360
350
BYPASS
START
DISPLAY
370
POWER
330
310
380
330

FIGURE 2



410
460
440
470
490
480
430
450
500
420
Number of wetting and Drying Cycles
Number of drying & wetting cycles
2
Number of suction steps
10
Time limit for saturation process
1
No wetting cycles
Wetting cycles
Suction & Equilibrium Time Limits
Step No
Suction cm Water
Time Limit (min)
Wakeup 18J
Send New Program to 18J
Quit
Time Now
2001/8/10 17:47:14
Started Time
2001/8/10 6:33:00
Current Progress
Get Data
Current Volume in the Tube
Manual Control
Setup Ports & Files
Suction
Time Limit
Wetting Cycles On
255
Data Received
Data Sent
Dhakshi is Ready to Receive Commands

FIGURE 3

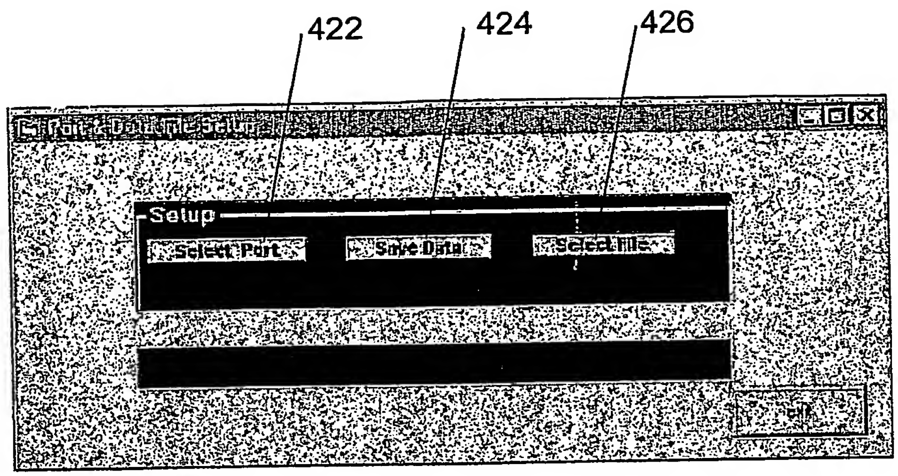


FIGURE 4

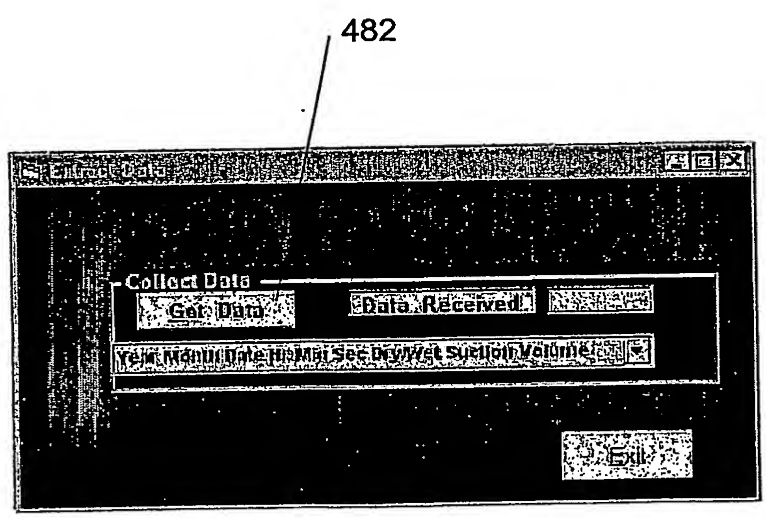


FIGURE 5

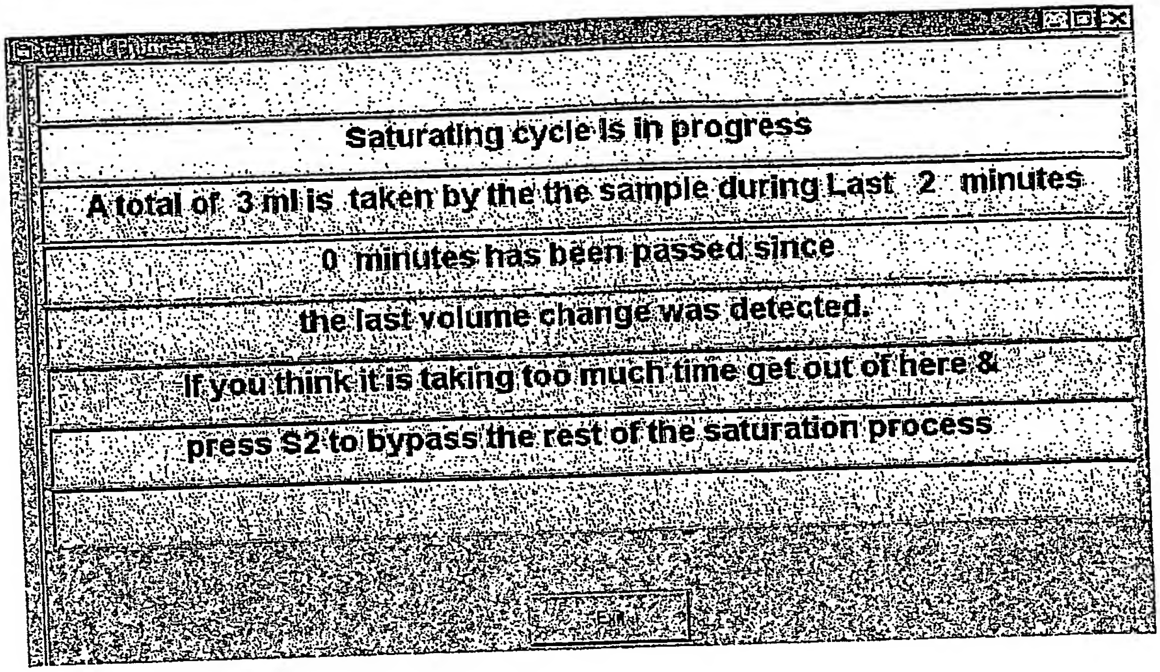


FIGURE 6

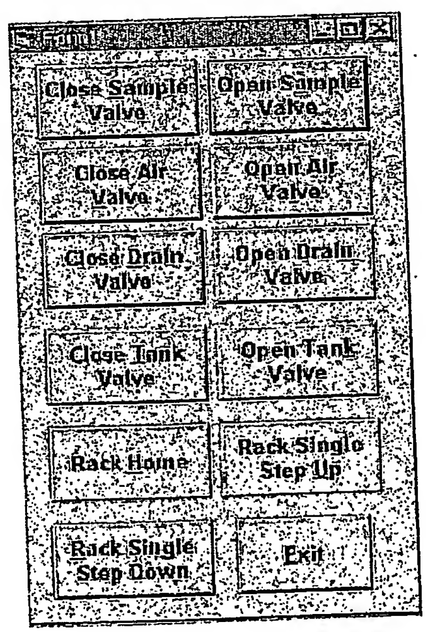


FIGURE 7

Volume given at the end of the string is the cumilative volume in number of segments. Multiply by 0.155 to get the volume in ml.

600

```
"                    **--J&J--** "
"  Automated Moisture Release Curve Apparauts          "

"           Programming Details          "

" Number of Dry/Wet Cycles Programmed =   ",2
" Number of Steps /Cycle              =   ",10
" Time Limit set for Saturation       =   ",1
" This Experiment was Started On      =   ","2001/8/10  6:33:00"
```

610

```
"           Current Status              "

"Current Cycle in Progress is a         =   ",2
"and it is at the Suction(cm Water)     =   ",0
```

620

```
" Number of Readings =  ",250

"   Step No      Suction     Time Limit "
"                step        Min "

"      1          8           2        "
"      2          8           2        "
"      3          16          2        "
"      4          8           2        "
"      5          16          2        "
"      6          8           2        "
"      7          8           2        "
"      8          8           2        "
"      9          8           2        "
"      10         8           2        "
```

630

"year. "	Month	Date	Hour	Min	Sec	Cycle	Suction cm Water	Cycleno	volume" ml"
"2001	8	10	6	48	3	Satura	0	0	6"
"2001	8	10	6	54	53	Satura	0	0	12"
"2001	8	10	7	1	50	Satura	0	0	18"
"2001	8	10	7	9	0	Satura	0	0	24"

640

FIGURE 8

FIGURE 9

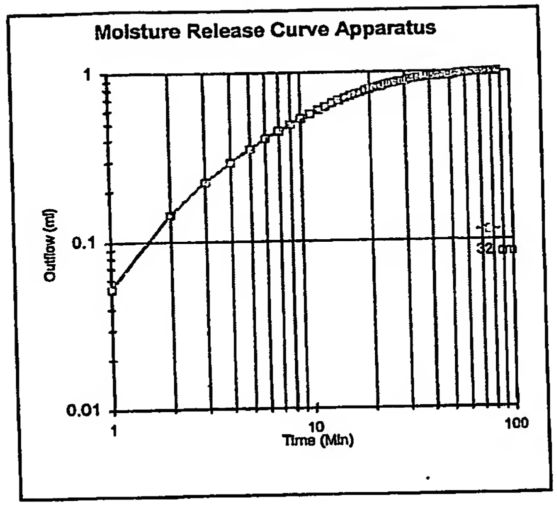


FIGURE 10

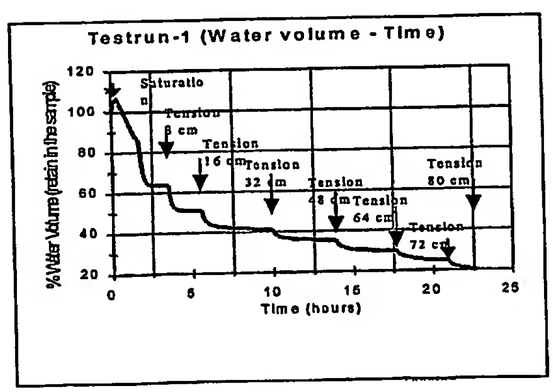


FIGURE 11

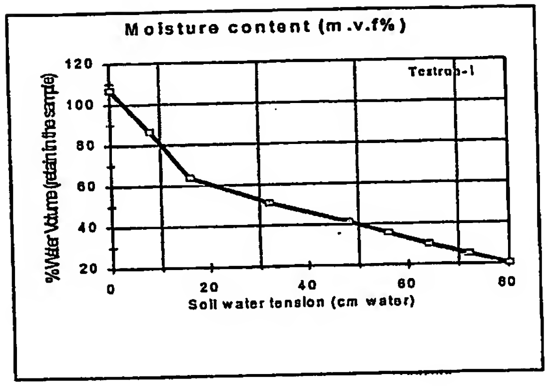


FIGURE 12

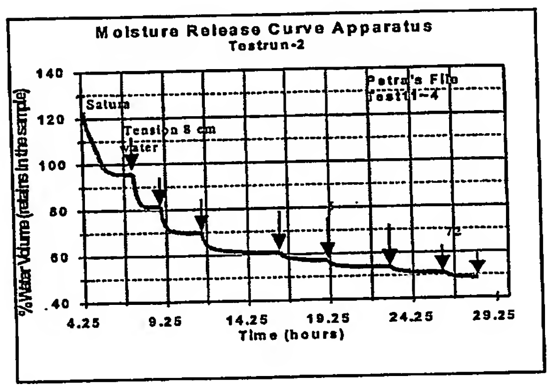


FIGURE 13